STATE OF DELAWARE
DEPARTMENT OF TRANSPORTATION
800 BAY ROAD
P.O. BOX 778
DOVER, DELAWARE 19903

CAROLANN WICKS, P.E.
SECRETARY

March 20, 2008

Dear Bridge Design Manual Holder:

SUBJECT: The Delaware Department of Transportation 2005 Bridge Design Manual - January 2008 Revision

This is the formal issuance of the January 2008 Revision to the Delaware Department of Transportation's 2005 Bridge Design Manual. This revision will be effective March 31, 2008. You can download this revision from DelDOT's web site, http://www.deldot.gov/information/pubs_forms/manuals/bridge_design/index.shtml. Changes have been made to Sections 3.4 and 3.4.1.1 regarding scour evaluation and protection.

Please replace the pages in your manual with the appropriate sheets. If you should have any questions, please contact Linda Osiecki at (302) 760-2342.

Sincerely yours,

Dennis M. O'Shea

Dennis M. O'Shea
Assistant Director - Design

DMO:los
cc: Robert Taylor, Chief Engineer
Kevin T. Canning, Quality Engineer
Linda M. Osiecki, Program Manager, Quality
Jiten Soneji, Bridge Design Engineer
George Spadafino, Quality Review Engineer
Keith Gray, FHWA

DelDOT

3.4 SCOUR EVALUATION AND PROTECTION

Changes in the bed level of a stream affect highway structures and may be described by three types of actions: (1) general scour (contraction scour), (2) local scour, and (3) degradation or aggradation of the stream channel. Scour and degradation are discussed in this section. Other types of erosion and aggradation are discussed in Section 3.5.

Every bridge over a waterway should be evaluated as to its vulnerability to scour in order to determine the appropriate protective measures. Most waterways can be expected to experience scour over a bridge's service life (which could approach 100 years). The need to ensure public safety and to minimize the adverse effects stemming from bridge closures requires the best effort to improve the state-of-practice of designing and maintaining bridge foundations to resist the effects of scour. Current information on this subject has been assembled in *HEC-18, Evaluating Scour at Bridges*.

Scour evaluations of new and existing bridges should be conducted by an interdisciplinary team composed of hydraulic, geotechnical, and structural engineers.

Bridges over waterways—both tidal and non-tidal—with scourable beds should withstand the effects of scour from a superflood (500-year flood) without failing.

Hydraulic studies shall include estimates of scour at bridge piers and evaluation of abutment stability. Bridge foundations shall be designed to withstand the effects of scour for the worst conditions resulting from floods. The geotechnical analysis of bridge foundations shall be performed on the basis that all streambed material in the scour prism above the total scour line for the designated flood (for scour) has been removed.

For the design flood, the stability of the bridge foundation shall be investigated using the service and strength limit states. The design flood for scour shall be the more severe of the 100-year event or from an overtopping event of smaller recurrence interval.

For the Q_{500} super flood conditions, the foundation shall be designed to be stable for the extreme event limit state. The super flood for scour shall be the more severe of the 500-year event or from an overtopping event of smaller recurrence interval.

In general, foundations shall be designed to be stable without relying on scour countermeasures. The only exception to this is when designing for local scour at abutments. Because the local scour equations tend to overestimate the magnitude of scour at abutments, they are generally used only to gain insight into the scour potential at an abutment. In most cases, a scour countermeasure, properly designed and installed in accordance with the procedures outlined in HEC-23, is provided to resist the local scour at abutments. Both the abutment foundation and the scour countermeasure must be designed to be stable after the effects of the estimated long-term degradation and contraction scour. Ensure that the top of the footing is below the sum of the long-term degradation, contraction scour, and lateral migration; stub abutments are an exception to this requirement, but the slopes in front of them should be adequately protected and/or sheeting should be provided to prevent undermining of the abutment and loss of fill. Riprap (minimum size R-5) must always be used to protect abutments from erosion for maintenance purposes, even if it is not required to resist the effects of local scour.

The *AASHTO Specifications* contain requirements for designing bridges to resist scour. Particular attention is directed to Sections 2.6.4.4.2 and 3.7.5.

3.4.1 EVALUATION CRITERIA

3.4.1.1 Analysis Procedure

Scour analysis should be performed according to the FHWA publication *HEC-18, Evaluating Scour at Bridges*. Computer software HY-9, Scour at Bridges, should be used to check the manual calculations. Any countermeasures required should be designed using the methods in:

- *HEC-18, Evaluating Scour at Bridges*,
- *HEC-11, Design of Riprap Revetment*,
- *FHWA-HI-90-016, Highways in the River Environment*,
- *HEC-20, Stream Stability at Highway Structures*, or
- *HEC-23, Bridge Scour and Stream Instability Countermeasures*.

Minimum riprap size must conform with the requirements of R-5 in Section 712 of the Standard Specifications. Larger riprap may be specified if it is needed. The riprap in the channel shall be covered with a minimum of one foot of natural stream bed channel. A low-flow channel shall be formed at that point, if applicable.

Also refer to *NCHRP Report 587, Countermeasures to Protect Bridge Abutments from Scour*.

3.4.1.2 Scourability of Rock

Evaluate the scour potential of rock by following the procedure for rock quality designation (RQD) in FHWA Mid-Atlantic Region Memorandum, Scourability of Rock Formations, to determine scourability. The following criteria represent the values to define rock quality and scourability of rock:

- The RQD value is a modified computation of the percent of rock core recovery that reflects the relative frequency of discontinuities and the compressibility of the rock mass and may indirectly be used as a measure of scourability. The RQD is determined by measuring and summing all the pieces of sound rock 6 inches [150 mm] and longer in a core run and dividing this by the total core run length. The RQD should be computed using NX diameter cores or larger and on samples from double tube core barrels. Scourability potential will increase as the quality of rock becomes poorer. Rock with an RQD value of less than 50 percent should be assumed to be soil-like with regard to scour potential.
- The primary intact rock property for foundation design is unconfined compressive strength (ASTM Test D2938). Although the strength of jointed rocks is generally less than individual units of the rock mass, the unconfined compressive strength provides an upper limit of the rock mass bearing capacity and an index value for rock classification. In general, samples with unconfined compressive strength below 250 psi [1724 kPa] are not considered to behave as rock. There is only a generalized correlation between unconfined compressive strength and scourability.
- The slake durability index (SDI as defined by the International Society of Rock Mechanics) is a test used on metamorphic and sedimentary rocks such as slate and shale. An SDI value of less than 90 indicates poor rock quality. The lower the value, the more scourable and less durable the rock.

- AASHTO Test T104 is a laboratory test for soundness of rock. A soaking procedure in magnesium and sodium sulfate solution is used. Generally the less sound the rock, the more scourable it will be. Threshold loss rates of 12 (sodium) and 18 (magnesium) can be used as an indirect measure of scour potential.
- The Los Angeles abrasion test (AASHTO T96) is an empirical test to assess abrasion of aggregates. In general, the less a material abrades during this test, the less it will scour. Loss percentages greater than 40 percent indicate scourable rock.

The other methods described in that memorandum should be used if required. For other soil types, existing surface borings and tests of soil samples should be interpreted.

3.4.1.3 Scour Evaluation Report

The scour evaluation report must contain the following items:

- table of contents;
- bridge description—bridge number, type, size, location, and National Bridge Inventory Record Item 113, Scour coding;
- executive summary of hydrologic and hydraulic methods, scour results, conclusions, and any countermeasure recommendations required, with plan and profile views showing scour depths and limits;
- scour computations (including computer input and output);
- bridge drawings, cross sections, soils information, test results, and other miscellaneous data; and
- references.

3.4.1.4 Plan Presentation

The following information will be provided in the Project Notes on the plans:

- a note stating that the structure has been analyzed for the effects of scour in accordance with the procedures described in *HEC-18, Evaluating Scour at Bridges*;
- scour analysis design flow volume, frequency, velocity, and water surface elevation;
- scour analysis check flow volume, frequency, velocity, and water surface evaluation;
- the calculated design scour depth; and
- the calculated check scour depth.

See Figure 3-6 for a sample scour project note.

Figure 3-6
Sample Scour Project Note

THE PROPOSED STRUCTURE HAS BEEN ANALYZED FOR THE EFFECTS OF SCOUR IN ACCORDANCE WITH HEC-18 - 'EVALUATING SCOUR AT BRIDGES' AND HEC-23 - 'BRIDGE SCOUR AND STREAM INSTABILITY COUNTERMEASURES.' SCOUR COUNTERMEASURES HAVE BEEN DESIGNED FOR THE WORST CASE OF THE OVERTOPPING FLOOD OR THE 500-YR FLOOD EVENT.

DESIGN EVENT	OVERTOPPING	DESIGN VELOCITY	6.22 FT/S
DESIGN DISCHARGE	535 CFS	DESIGN DEPTH OF FLOW	6.14 FT

3.5 STREAM STABILITY

3.5.1 STREAM STABILITY ANALYSIS

Erosion is considered to be the loss of material on side slopes and stream banks. Types of stream erosion include:

- scour (see Section 3.4);
- the natural tendency of streams to meander within the flood plain;
- bank erosion; and
- degradation.

These are all interrelated to some degree.

The computed velocity is a measure of the potential erosion and scour. Exit velocity from culverts will be computed on the assumptions shown in *HDS-5, Hydraulic Design of Highway Culverts*. (Use HY-8, Culvert Analysis, software based on HDS-5 for the computations.) Average velocity computed on the gross waterway will be the representative velocity for open span structures, furnished by computer analysis for water surface elevations.

Examples of highly erodible soil can be found in all areas of the state. Areas of loamy deposits, which are highly sensitive to erosion, are prevalent in Delaware. County SCS soil maps may aid in judging the in-situ material.

The designer must consider the downstream erosion potential in evaluating and sizing the structure. Under some conditions, any additional erosion would be intolerable. Thus, risk considerations should be included in the site study. It should be recognized that stream banks erode regardless of the presence of a highway crossing. Any alteration of erosion potential by a structure must be closely evaluated in judging the adequacy of a design.

Streams naturally tend to seek their own gradient through either degradation or aggradation. Degradation is the erosion of streambed material, which lowers the streambed. Aggradation is the transport and deposition of the eroded material to change the streambed at another location. The effect of the structure on degradation or aggradation of a stream must be evaluated in bridge crossing design.

The designer should evaluate the stability of the bed and banks of the waterway channel, including lateral movement, aggradation, and degradation, using *HEC-20, Stream Stability at Highway Structures*.

3.5.2 BANK PROTECTION

The most common method of bank protection is the use of rock riprap. Factors to consider in the design of rock riprap protection include:

- the stream velocity,
- the angle of the side slopes, and
- the size of the rock.

Filter blankets of smaller gradation bedding stone or geotextiles are used under riprap to stabilize the subsoil and prevent piping damage. Riprap bank protection should terminate with a flexible cut-off wall.

The designer should specify a minimum blanket thickness of 18 inches [460 mm] for embankment protection and 24 inches [610 mm] for slope protection along stream banks and for streambeds. Refer to *FHWA-HI-90-016, Highways in River Environment*, and *HEC-11, Design of Riprap Revetment*. See Figure 3-7 for typical riprap details and an example of a riprap installation.

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CAROLANN WICKS, P.E.
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May 6, 2008

Dear Bridge Design Manual Holder:

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This is the formal issuance of the April 2008 revision to the Delaware Department of Transportation's 2005 Bridge Design Manual. This revision will be effective May 12, 2008. You can download this revision from DelDOT's web site, http://www.deldot.gov/information/pubs_ forms/manuals/bridge_design/index.shtml. Section 8.1.3 regarding covered bridge painting has been added.

Please replace the pages of your manual with the appropriate sheets. If you should have any questions, please contact Linda Osiecki at (302) 760-2342.

Sincerely yours,

Dennis O'Shea
Assistant Director – Design

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cc: Robert Taylor, Chief Engineer
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DelDOT

Chapter Eight

Timber Structures Design

8.1 INTRODUCTION

As of 2005, almost three percent of Delaware's bridges were timber.

DelDOT's construction of timber bridges has decreased in proportion to its use of other materials over the last 50 years. This is due to an increasing use of steel and concrete to accommodate longer spans, increased traffic and larger truck loads. Today, most new timber bridges constructed by DelDOT are single spans over tax ditches and creeks on low-volume roads.

Other uses of timber by DelDOT include piles, barriers, railings, boardwalks, decks, fender systems, privacy fences, landscaping, railroad ties, and retaining walls.

This chapter will discuss general aspects of timber bridges, physical and mechanical properties of timber, preservatives, hardware, design criteria, and the design of various components of bridges using wood. These topics will be discussed in enough detail to give designers the insight needed to design timber bridges that are constructable, functional, durable, and maintainable. Emphasis will be placed on the types of timber bridges in use on the state's highway system. Where appropriate, the designer is referred to other references for details not presented here.

8.1.1 ADVANTAGES AND DISADVANTAGES OF TIMBER BRIDGES

The main advantages of timber bridges relative to other bridge materials are:

- Ease of construction;
- Ease of maintenance;
- Pleasing appearance;
- Renewable resource;
- Consstruction is not weather-dependent;
- Lightweight.

The main disadvantages of timber bridges are:

- Susceptibility to vandalism.
- Rapid decay in the absence of proper treatment.
- The need to account for irregularities in the material in design and construction.
- Frequent maintenance requirements.

8.1.2 TIMBER AS A BRIDGE MATERIAL

Timber can be used to construct many different types of bridge systems. In Delaware, some of them are:

- Beam
- Deck
- Truss

Most timber bridges currently being built in the state are laminated deck type systems. However, many beam type systems constructed prior to the 1960's are still in DelDOT's bridge inventory.

Many different qualities and species of wood are available for construction. Because of the large variation in timber qualities, the bridge designer must carefully specify wood materials. This is to insure that the timber specified is available, durable, and can safely carry the design loads and satisfy serviceability limit states.

Construction of timber beam and deck bridge systems in Delaware is carried out using various types of lumber. Variations in lumber used in bridge construction include:

- Species of the tree;
- Physical properties of the lumber;
- Mechanical properties of the lumber;
- Sawn or laminated lumber;
- Preservative treatments.

Additional design considerations are:

- Superstructure type;
- Types of fasteners;
- Railings;
- Wearing surfaces;
- Fire resistance and/or protection;
- Substructure type.

8.1.2.1 TIMBER BEAM SUPERSTRUCTURE

Beam type systems are the simplest type of timber bridge. Most consist of a series of longitudinal beams supported by piers and abutments. Typically spans can range from 10 to 30 ft [3 to 9 m] depending on the beam type. Most of the bridges of this type on Delaware's highway system were built prior to the 1960's. Timber beam systems include:

- Sawn Lumber Beams
- Glue Laminated Beams

Most timber beam type bridges in Delaware are sawn lumber beams, and most range in span from 10 to 20 ft [3 to 6 m]. The beams are typically less than 3 feet [1 m] apart, and are commonly 4 to 8 in [100 to 200 mm] wide and 12 to 18 in [300 to 450 mm] deep. Decks on beam superstructures are typically constructed of 2 to 4 in [50 to 100 mm] thick planks placed transverse to the beams. The planks are typically not overlaid with a wearing surface, because they deflect under load, causing cracking of the wearing surface.

8.1.2.2 LONGITUDINAL DECK SUPERSTRUCTURES

Longitudinal deck superstructures are the primary types of timber bridges currently being constructed in Delaware. Longitudinal deck superstructures are constructed by glue laminating timber planks together to form panels, and then, if possible, stress laminating the panels together to form a rigid deck unit. The deck is typically overlaid with hot-mix. See Section 8.7 for more design details.

Longitudinal deck superstructures are typically between 8 and 16 in [200 and 400 mm] deep. They can be used economically and practically for clear spans up to approximately 30 ft [9 m]. The low profile of these bridges makes them desirable when vertical clearance below the bridge is limited.

8.1.3 COVERED BRIDGE PAINTING

Uniform paint colors shall be used for all covered bridges in Delaware as follows:

- Primary Color for Siding/Exterior - Red Federal Standard 595 Color 20152
- Secondary Color for Trim - White Federal Standard 595 Color 37925

The paint shall be a flat finish (low luster). The plans shall note which of these colors shall be used in other locations.

8.2 PHYSICAL PROPERTIES OF STRUCTURAL TIMBER

Physical properties of wood refer to its natural qualities. Numerous factors have an effect on the physical properties of wood. Designers must be aware of these factors and specify allowable mechanical properties for use in design. Mechanical properties of lumber are discussed in Section 8.3. Factors having an effect on the physical properties of wood are:

- Species
- Direction of grain
- Moisture content
- Density
- Knots
- Durability

8.2.1 LUMBER SPECIES

Lumber is manufactured from a great variety of timber species. Physical properties of each species vary. Some species of timber are strong and durable, while others are not. Species with similar mechanical properties are classified into groups. Typically, several species suitable for bridge construction are available in a given location. In Delaware, the preferred species for use in bridge construction are Douglas fir and southern yellow pine. For the replacement of historic covered bridges, the exotic fire-resistant wood bongossi/azobe (Lophira alata) may be used with the approval of the Bridge Design Engineer.

8.2.2 DIRECTION OF GRAIN

Wood grows as fibers that run in the direction of the tree trunk. Parallel to the wood fibers is “with the grain”. Perpendicular to the direction of the fibers is “against the grain”. Wood has different structural properties in each of these directions, which must be accounted for in design.

8.2.3 MOISTURE CONTENT

Moisture content of wood is the weight of water it contains divided by its dry weight. Moisture content is typically expressed as a percentage. Moisture content of timber varies by species and structural application. Wood is a hygroscopic material, which means that it absorbs moisture in humid environments and loses moisture in dry environments. As the moisture content of wood changes, so does its strength. Wood with lower moisture content has higher strength. The factors used to make strength adjustments based on changes in the physical condition of wood are given in Section 8.3.4.2. Moisture content of wood used in timber bridges is a function of use above or below the water line, temperature, and humidity.

As the moisture content of wood changes, wood shrinks and swells. With the grain, average shrinkage values for green to oven dry conditions range between 0.1 and 0.2 percent; this is generally of no concern to the designer. Against the grain, shrinkage is much more pronounced. The effect of uneven drying in two different directions perpendicular to the grain can cause wood to warp. This commonly occurs in thin planks. Typically, bridge designers do not have to make shrinkage calculations; however, they should understand how shrinkage occurs and guard against its detrimental effects.

8.2.4 DENSITY

Density of wood varies with species and moisture content. Density for most species varies between 20 and 50 pcf [320 and 800 kg/m^3]. For most bridge applications, density is taken as 50 pcf [800 kg/m^3]. The density of bongossi is 66 pcf to 75 pcf [1060 to 1205 kg/m^3]. Density of wood and strength are closely related. Generally, as density increases, strength increases proportionally. Density is also important in buoyancy calculations.

8.2.5 KNOTS

Knots are formed by a branch that has been surrounded by growth of the trunk. Knots reduce the strength of wood because they interrupt the continuity and direction of wood fibers.

8.2.6 DURABILITY

The natural durability of wood is defined as its resistance to decay and insect attack. Natural durability of wood varies with species. In general, only the heartwood of a tree is considered naturally durable. Heartwood is the interior of the tree trunk which is composed of inactive wood cells. Because of variations in durability, it is unreliable for the bridge designer to depend on natural wood durability in structural applications. Therefore, the wood used in structural applications is treated to resist decay and attack from insects. Preservative treatments for wood will be further discussed in Section 8.4.

8.3 MECHANICAL PROPERTIES

Mechanical properties describe the characteristics of a material in response to externally applied forces. Designers are mainly concerned with elastic and strength properties.

Elastic properties relate a material's resistance to deformation under an applied load and ability of the material to regain its original dimensions when the load is removed. There are three elastic properties of wood: modulus of elasticity, shear modulus, and Poisson's ratio. Each of these elastic properties has different values depending on species, grade, and orientation of the applied load to the direction of the grain. The only elastic property of wood that is typically required in bridge design is modulus of elasticity in the longitudinal direction. This value relates the stress occurring in that direction to the strain occurring along the same axis.

Strength properties describe the ultimate resistance of a material to applied loads. They include compression, tension, shear, bending, and torsion. As with elastic properties, strength properties of wood vary in different directions along the grain and with species and grade.

Mechanical properties of wood vary greatly. Even timber members cut from the same log can have widely varying mechanical properties. The mechanical properties of any given member are a direct result of its inherent physical properties. This leads to a fairly elaborate system for both lumber grading at the mill and determination of mechanical properties to be used in design. Wood strength and elastic design values are found in the *AASHTO Specifications*, Section 8.4.

8.3.1 SAWN LUMBER GRADING

Mechanical properties of sawn lumber are a function of species, physical condition of the member, size, and structural application.

Most timber bridges currently being built in the state are laminated deck type systems. However, many beam type systems constructed prior to the 1960's are still in DelDOT's bridge inventory.

Many different qualities and species of wood are available for construction. Because of the large variation in timber qualities, the bridge designer must carefully specify wood materials. This is to insure that the timber specified is available, durable, and can safely carry the design loads and satisfy serviceability limit states.

Construction of timber beam and deck bridge systems in Delaware is carried out using various types of lumber. Variations in lumber used in bridge construction include:

- Species of the tree;
- Physical properties of the lumber;
- Mechanical properties of the lumber;
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Additional design considerations are:

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- Types of fasteners;
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- Durability

8.2.1 LUMBER SPECIES

Lumber is manufactured from a great variety of timber species. Physical properties of each species vary. Some species of timber are strong and durable, while others are not. Species with similar mechanical properties are classified into groups. Typically, several species suitable for bridge construction are available in a given location. In Delaware, the preferred species for use in bridge construction are Douglas fir and southern yellow pine. For the replacement of historic covered bridges, the exotic fire-resistant wood bongossi/azobe (Lophira alata) may be used with the approval of the Bridge Design Engineer.

8.2.2 DIRECTION OF GRAIN

Wood grows as fibers that run in the direction of the tree trunk. Parallel to the wood fibers is “with the grain”. Perpendicular to the direction of the fibers is “against the grain”. Wood has different structural properties in each of these directions, which must be accounted for in design.

8.2.3 MOISTURE CONTENT

Moisture content of wood is the weight of water it contains divided by its dry weight. Moisture content is typically expressed as a percentage. Moisture content of timber varies by species and structural application. Wood is a hygroscopic material, which means that it absorbs moisture in humid environments and loses moisture in dry environments. As the moisture content of wood changes, so does its strength. Wood with lower moisture content has higher strength. The factors used to make strength adjustments based on changes in the physical condition of wood are given in Section 8.3.4.2. Moisture content of wood used in timber bridges is a function of use above or below the water line, temperature, and humidity.

As the moisture content of wood changes, wood shrinks and swells. With the grain, average shrinkage values for green to oven dry conditions range between 0.1 and 0.2 percent; this is generally of no concern to the designer. Against the grain, shrinkage is much more pronounced. The effect of uneven drying in two different directions perpendicular to the grain can cause wood to warp. This commonly occurs in thin planks. Typically, bridge designers do not have to make shrinkage calculations; however, they should understand how

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CAROLANN WICKS, P.E.
SECRETARY

May 12, 2009

Dear Bridge Design Manual Holder:

SUBJECT: The Delaware Department of Transportation 2005 Bridge Design Manual - April 2009 Revision

This is the formal issuance of the April 2009 Revision to the Delaware Department of Transportation's 2005 Bridge Design Manual. This revision will be effective May 20, 2009. You can download this revision from DelDOT's web site, http://www.deldot.gov/information/pubs_forms/manuals/bridge_design/index.shtml. The web site also includes the revision with changes highlighted for your reference. Changes have been made to Chapters 2, 4 and 13, resulting from additional criteria regarding loads during construction and types of construction.

Please replace the pages in your manual with the appropriate sheets. If you should have any questions, please contact Linda Osiecki at (302) 760-2342.

Sincerely yours,

Dennis M. O'Shea

Dennis M. O'Shea
Assistant Director - Design

DMO:lob
cc: Natalie Barnhart, Chief Engineer
Jiten Soneji, Bridge Design Engineer
Kevin T. Canning, Quality Engineer
Linda M. Osiecki, Program Manager, Quality

DelDOT

Chapter Fourteen – RESERVED

Appendix A – Design References

2.4.1 GUIDELINES

In selecting bridge types, the designer should consider these factors:

- Prestressed concrete beams should be considered for spans up to 90 feet [27 m].
- For spans greater than 90 feet [27 m] where beams can be transported to the site economically, concrete girders can be considered.
- For spans greater than 100 feet [30 m] where highway transportation must be used, steel girders should be considered.
- The use of precast concrete deck sections instead of cast-in-place deck will reduce construction time.
- Consider concrete girders for bridges over water.
- The use of weathering steel over waterways with low clearance is discouraged.
- Use concrete or weathering steel girders over electrified railways to eliminate the hazards associated with repainting.
- Limit the use of timber bridges to low-volume roads—roads with ADT under 750 and less than 10 percent trucks.

Refer to Chapter 7 for culvert material guidelines.

For many locations, a particular bridge type will be the obvious choice. However, where the choice is not obvious, alternative bridge types must be considered.

For non-major structures, an evaluation should be made to determine the best type of structure for a specific location. The designer should consider these factors:

- the initial construction cost;
- life-cycle costs;
- site-specific problems and conditions;
- traffic problems and detour costs;
- construction time and sequence;
- construction scheduling;
- potential maintenance problems and costs;
- environmental impact;
- durability;
- clearance requirements;
- aesthetics, especially in historic areas;
- public input;
- construction feasibility; and
- in-service inspectability.

In the design of major structures, a formal evaluation of the different types of bridges should be made to determine the optimum type for the specific location. The evaluation procedure is not fixed. The conditions encountered should be evaluated for each specific location. Figure 2-1 shows an example of an evaluation matrix. The evaluation procedure, the criteria used, and the weight given to each criterion must be adapted for the conditions encountered at each bridge site and be approved by the Bridge Design Engineer. The evaluation should include life-cycle costs if at all possible. Maintenance costs of the alternatives must be known or accurately estimated to provide accurate costs for comparison.

2.4.2 ALTERNATIVE DESIGNS

In a few cases, two alternative designs may be desirable for major structures, if approved by the Assistant Director, Design. Normally, one design will be for steel superstructure and the other for concrete. Other materials may be considered.

Figure 2-1
Example Evaluation Matrix

Criterion	Weight, α	Alternate Rating, R		
		A	**B**	**C**
Probable cost	0.40	10	9	8
Aesthetics	0.15	9	9	10
Constructibility	0.10	10	9	7
Maintainability	0.10	10	10	10
Environmental Impact	0.10	9	9	10
Durability	0.05	10	10	10
Inspectability	0.05	10	10	10
Rideability	0.05	10	10	10
Final Rating	**1.00**	**9.75**	**9.25**	**8.9**

Notes:
1. Rating (R) is a flexible scale from 1 (least desirable) to 10 (most desirable).
2. Final Rating = $\Sigma \alpha_i R_i$

2.4.3 VALUE ENGINEERING

The Federal Highway Administration (FHWA) requires value engineering for major projects — those with total estimated costs equal to or greater than $25 million on the National Highway System (NHS). The value engineering process is outlined in Policy Implement D-05.

2.5 DESIGN CONSIDERATIONS

In addition to the structural design specifications listed in Section 2.2, there are related areas that the designer must consider. These areas include historic requirements, maintenance of traffic, constructibility, provisions for inspection, and future widening.

2.5.1 DESIGN REQUIREMENTS

Bridge designs must meet AASHTO and DelDOT design practices and must comply with local requirements, such as historical, drainage and environmental regulations.

2.5.2 MAINTENANCE OF TRAFFIC

Unless the bridge is on a new location, maintenance of traffic during construction must be considered in any bridge design. Options for maintaining traffic include:

- detouring traffic to existing roadways so the bridge site can be closed to traffic;
- constructing a temporary bridge and detour; or
- using staged construction to allow traffic to be maintained on the portion not under construction.

Any restrictions on the closing of lanes must be included in the contract documents. Restrictions may include:

- special events, such as car races, the state fair, and long holiday weekends;

- school bus routes while school is in session;
- routes with heavy tourist traffic during summer months;
- daily work hour restrictions to accommodate rush-hour traffic; and
- city or county restrictions.

Intermediate contract milestones may be used on multi-staged projects. Restrictions that impede the contractor's ability to work on the project must be considered in the determination of working time. The need for restrictions should be determined early in the design phase.

2.5.3 CONSTRUCTIBILITY

One aspect of an economical design is that it can be constructed with conventional equipment by the contractors who typically bid Delaware projects. Designers should become familiar with current local bridge construction practices so most designs can be built with conventional equipment.

Designs should be reviewed to identify any of the following potential construction problems:

- Can the structure actually be constructed in accordance with the plans?
- How will each component will be constructed?
- Is the sequence of construction practical?
- How will forms and temporary sheet piles be removed?
- How will beams be transported and erected?
- How will utility relocations affect the schedule?
- How will traffic be maintained at each stage of construction?
- How will the contractor access the site?
- How will the stream flow be maintained?
- How will the work area be de-watered?

The constructibility review should include a simulation of construction sequencing requirements on the project. An on-site review may be necessary to ensure that all project elements are considered in the constructibility review. District, Quality and Construction personnel can assist with constructibility reviews.

2.5.4 DESIGN FOR MAINTENANCE

All bridges will eventually require maintenance and repair. Designers should consider how the bridge will be inspected, serviced and repaired when developing the designs and plans.

2.5.4.1 Maintainability

Designers should request the Bridge Management Section to comment on specific problems they encounter on the various types of bridges or specific details, such as bearings and joints, so that designs can be improved to minimize maintenance problems. The goal is to design a maintenance-free bridge, insofar as that is possible.

Some items critical to maintenance operations include the following:

- Joints
    - Design jointless bridges when possible.
    - Design joints to be sealed to prevent water ingress to the bearings and supports below the joint.
    - Avoid unusual joint details.
    - Provide joint components that can be maintained.
    - Minimize the number of expansion joints.

    - When finger joints are necessary, use drainage troughs.
- Provide for jacking to facilitate servicing, repairing, or replacing bridge bearings.
- Provide access for maintenance to all bridge components that are not accessible with an under bridge inspection vehicle (UBIV) or other means.
- Avoid superstructure details that trap dirt in the splices, joints, or other components that cause corrosion.
- Provide maintenance and operating manuals for movable bridges and other complex structures.
- Design deck drains to carry the water below the beams to prevent water damage from splash-back.
- Provide downspouts where deck drains would cause erosion or dump water on roadways from overpasses.
- Design deck drainage systems sufficient in size and with adequate slope to prevent clogging and ponding. Provide clean-outs. Avoid sharp bends that may cause clogging.
- Specify structural steel only where it can be repainted safely and economically; otherwise, use weathering steel or other low-maintenance materials.
- Protect stream channel banks from erosion and piers and abutments from scour.
- Provide for roadway runoff drainage and slope protection at abutments and wingwalls.
- Provide adequate vertical and horizontal clearances to prevent damage from traffic impacts.

The above items are not a comprehensive list but are intended to make the designer aware of the importance of maintenance considerations.

2.5.4.2 Provisions for Inspection

All bridges must be inspected regularly to ensure the integrity of the structure and its components. Bridge safety inspectors must be able to visually check all components of each bridge at arm's length. Designs should include a means of access to facilitate these inspections. Many bridges may be inspected from ladders. UBIV’s are effective for inspecting the outer portions of the superstructure, but do not provide access to the center beams on wider structures. Catwalks or other means of access may be necessary. Other considerations for inspections include the following:

- Provide shoulders wide enough to accommodate the UBIV without impeding traffic.
- List critical inspection items, such as fracture critical members, on the plans to advise bridge safety inspectors.
- Ensure that bridge components are accessible for inspection.
- Provide access with proper ventilation to the interiors of box girders for bridge safety inspections. Provide outlets for lighting or install an interior lighting system. Painting the interior of box girders white or another light color makes inspection easier.
- Design bridges so they can be inspected easily. Make openings and accesses wide enough and place them logistically so inspectors can get into them.
- Provide at least 4 feet [1.2 m] of underclearance on all bridges so the underside of the superstructure can be inspected with a boat. Tidal bridges can be inspected at low tide. However, provide at least 1 foot [0.3 m] of underclearance from high tide and 4 feet [1.2 m] from low tide.
- Make box culverts at least 4 feet [1.2 m] tall.

2.5.5 FUTURE WIDENING

When it is reasonably certain that the bridge will have to be widened in the near future, the substructure should be designed to accommodate the widening. The substructure on the median side of divided highways should be constructed with the original bridge because of the difficulty of constructing it under traffic.

2.5.6 CONTEXT SENSITIVE DESIGN

A context sensitive design simultaneously advances the objectives of safety, mobility, enhancement of the natural environment, and preservation of community values. All bridge projects should balance these objectives as appropriate for each location. Designers should use the flexibility within the *Road Design Manual* to achieve these objectives. Guidance is available from the FHWA *Flexibility in Highway Design* and the *Green Book*.

2.6 DESIGN LOADS

DelDOT adopts all AASHTO design loads and Delaware legal loads.

2.6.1 LIVE LOADS

Refer to the *AASHTO Specifications* for AASHTO live loads.

The above loadings are for load ratings. These loadings are not used for LRFD.

2.6.2 DEAD LOADS

Refer to Section 3.5, Permanent Loads, in the *AASHTO Specifications*.

2.6.3 CONSTRUCTION LOADS

During design, all primary members, including connections, shall be analyzed for anticipated construction loads. The designer shall review as-built plans, archived shop drawings, and previous inspection notes and drawings, along with personal field inspection to ensure the size and condition of structural members. All stresses for existing and proposed members shall be within allowable ranges for strength, service, and fatigue as directed by the *AASHTO Specifications*.

Analysis shall be required for shifting travel lanes to shoulders, anticipated stockpiling of materials or equipment (including crane loading), or any other significant loading anticipated.

Plan notes and specifications shall be clearly written to limit construction equipment and stockpile sizes to ensure members stay within allowable stress limits and to direct the contractor to provide calculations and shop drawings for any deviation.

2.7 BRIDGE LOAD RATING

The designer is required to calculate load ratings for all structures as a part of the design. This requirement applies to all structures—complete replacement, rehabilitation, or new bridge. Refer to Chapter 4 for load rating requirements. In addition to the design of the structure using HL-93, a minimum inventory rating of one will be achieved for all Delaware legal loads.

The calculated ratings must be included in the project notes of the contract plans. Refer to Figure 4-2 for a sample summary format.

2.8 PLAN PRESENTATION

Bridge construction plans shall conform to DelDOT standards.

2.8.1 DRAFTING STANDARDS

Standard line widths, lettering sizes, fonts, and symbols have been established to promote uniformity in the preparation of bridge design plans. Refer to the *CADD Manual* for general Department drafting standards. The use of these standards will ensure that plans are readable and easily interpreted by field and contractor personnel.

2.8.2 PLAN SHEET SEQUENCE

Bridge project plans will be assembled in the following order:

- Title Sheet and Index of Sheets,
- General Notes and Project Notes,
- Roadway Detail Sheets,
- Typical Sections,
- Plan and Profile Sheets,
- Bridge Sheets,
- Environmental Compliance Sheet,
- Erosion Control Plan Sheets,
- Utility Sheets (if applicable),
- Traffic Control Plan Sheets,
- Traffic Sheets,
- Right-of-Way Sheets (if applicable), and
- Quantity Sheets.

Bridge sheets are assembled in the order of construction—foundation details first, followed by columns, caps, etc. as follows:

- Bridge Plan, Section and Elevation
- Foundation Layout
- Pile Details
- Abutment Details
- Pier Details
- Bearing Details
- Framing Details
- Beam Details
- Diaphragm Details
- Camber Details
- Deck and Parapet Details
- Finished Deck Elevations
- Expansion Joint Details
- Approach Slab Details
- Miscellaneous Details
- Reinforcing Bar List
- Soil Borings
- Guardrail Details

Quantity sheets must provide a separate quantity summary for each bridge as well as a total project quantity summary.

Sheets may be combined on smaller projects to reduce the number of sheets. Except for the Bridge Sheets and Soil Borings, follow the *CADD Manual* for preparing all sheets.

2.8.3 BRIDGE SHEET PREPARATION

General instructions for completing bridge sheets are presented below. Specific plan presentation instructions are shown in each chapter, as appropriate.

2.8.3.1 General and Project Notes

General Notes include items that are applicable to all projects. The Quality section maintains a General Notes and Legend sheet. The most recent version of this sheet shall be used on all projects. General notes include such items as:

- specifications;
- erosion control site reviewer requirements; and
- other notes not addressed by the Standard Specifications.

Project notes include items that are specific or unique to the project. Bridge project notes include:

- design criteria;
- vertical and horizontal datum;
- hydraulic and scour data;
- design loading;
- portland cement concrete class and/or strength;
- reinforcing steel specification and grade;
- prestressing steel specification and grade;
- structural steel specification and grade;
- foundation information;
- removal items;
- utilities;
- traffic control references;
- the calculated load ratings (see Chapter 4); and
- other specific project-related notes.

2.8.3.2 Bridge Sheets

The number of bridge sheets will vary with the size and complexity of the structure. As a minimum, the bridge sheets will show:

- a plan view and elevation view;
- typical roadway and bridge sections;
- substructure details;
- superstructure details;
- railing and parapet details;
- reinforcement; and
- borings.

Normally, a separate sheet is used for each abutment and pier. Where piles are used, a pile layout should be provided for each substructure unit.

In addition, as appropriate, the bridge sheets will show the following:

- deck details including grades;
- joint details;
- camber diagrams;
- pouring sequence; and
- other details necessary for constructing the bridge.

2.8.4 MINIMUM-DETAIL PLANS

Minimum-detail plans are used for minor bridge projects such as bridge painting, bridge scour or emergency projects. These plans are typically on 8 ½”x11” sheets.

2.8.5 OTHER PLAN SHEETS

Refer to the *Project Development Manual* for instructions on the preparation of:

- title sheets;
- right-of-way plans;
- revisions and addendums; and
- as-built plans.

2.9 BRIDGE DESIGN PROCEDURES

2.9.1 INTRODUCTION

2.9.1.1 Designed-In Value

Designed-in value is quality: quality design; quality plans, specifications and estimates; quality construction methods; and quality construction results. Clear contract documents contribute significantly to quality construction. It is the designer’s responsibility to produce quality designs and clear contract documents.

The need for bridge improvements is generally greater than funds available to meet those needs. Consequently, bridge designs must provide long-lasting structures that require limited maintenance with funds available for the project. There are several methods available to assist the designer in developing the best possible design. The principles of value engineering and life-cycle cost analysis are appropriate for evaluating alternatives for bridge locations, materials, components, and bridge types.

Value engineering is defined as the systematic application of recognized techniques that identify the function of a product or service, establish a value for that function, generate alternatives, and provide the function reliably at the lowest overall cost. While formal value engineering analyses usually are conducted by a multidisciplinary team, there are several value engineering principles that can be used by a designer during the design of a new bridge or rehabilitation of an old one. These include:

- developing good design procedures;
- adhering to procedures;
- determining the optimum solution to the problem—neither overdesigning nor underdesigning; and
- finding the highest value alternative over the life of the bridge, not the cheapest one.

Life-cycle cost analyses can also be applied to overall projects or project elements to assist in determining the best alternative. The following should be considered:

- design costs;
- construction costs;
- right-of-way costs;
- routine maintenance costs;
- periodic maintenance and rehabilitation costs;
- service life (typically 75 years);
- operating costs;
- accident costs; and
- user costs.

A quality design should provide a long service life with minimal maintenance. The designer should utilize the experience of the Department staff in preparing plan details by applying "lessons learned" from previous projects. All structures require maintenance, but some types of details require more frequent maintenance. The better details should consistently be used and further refined. This provides construction economy as well as minimal maintenance. Decisions made in the design phase will affect the cost of operation and maintenance of the facility for as long as it is in use.

A balance between available funds and optimal design must be achieved to provide the maximum benefits to the public. Through designed-in value, the optimum improvements can be accomplished for the available funds to provide a reasonable service life.

2.9.1.2 Documentation of Design

The design of each bridge must be documented to provide a permanent reference for future use. This reference may be used for answering questions during construction, bridge safety inspections, maintenance, and when major rehabilitation or reconstruction is necessary.

Documentation of the design should include the following:

- design computations;
- specific references to specifications;
- assumptions;
- specific design criteria;
- hydraulic and hydrology reports;
- foundation reports;
- quantity calculations;
- materials properties;
- computer printouts, if the design was prepared on the computer (including

input, output, and the name and version of the software);

- design checklist; and
- any design exceptions.

The documentation should be kept in notebooks or folders for permanent storage in the contract file. With each plan submission, a copy of design computations and printouts shall be submitted so that they can be reviewed; they must include the date and the name/initials of the designer who performed the computations and the person who checked them on each sheet. Added to this will be the date and the name/initials of the DelDOT reviewer following review of the computations. The cover sheet for the calculations shall have signature lines for the designer, checker and reviewer to recommend what is contained therein. By the final plan submission, consultant designers should submit all of the original documentation to the Bridge Design Engineer. Any changes to the documentation should be submitted by the time construction is completed.

2.9.1.3 Stewardship Agreement

The Stewardship Agreement between DelDOT and FHWA defines responsibilities for program, project, and process reviews. This agreement is updated annually; the most recent agreement should be referred to. Under this Agreement, all federal-aid projects will be reviewed and approved within DelDOT and not involve FHWA unless:

- the project is a 3R or 4R project on the Interstate System (NHS) and the estimated construction cost exceeds one million dollars;
- the project is a 4R project on the National Highway System (NHS) and the estimated construction cost exceeds one million dollars;
- the project is a bridge estimated to cost more than 10 million dollars; or
- the project is unique and the Department requests FHWA involvement.

Since project costs tend to escalate through the design process, all federal-aid projects on the NHS should be reviewed with the Bridge Design Engineer at initiation to determine whether FHWA should be involved.

A 4R bridge project shall be defined as a project involving complete bridge replacement or rehabilitation including complete deck replacement. A bridge preservation project shall be defined as one that does not include complete deck replacement. These projects may include such items as deck overlay, joint replacement, cleaning and painting, seismic retrofit, scour countermeasure installation, and substructure rehabilitation.

2.9.1.4 Design Consultants

Design consultants are engaged to supplement in-house design staff and for design of unique structures. Consultants are selected through the Department's selection process. Design contracts are typically open-end contracts for a specified time period with an upset fee limit. The successful consultants are assigned projects for design as needed during the contract period. Assigned projects are scoped with the consultant, who then prepares a formal scope and cost proposal for the design. Upon approval of the cost proposal and funding, the Bridge Design Engineer issues a notice to proceed. Refer to the *Professional Services Procurement Manual* for more detail.

The Bridge Design Project Manager monitors consultant progress and conducts periodic technical reviews on open-end consultant contracts, similar to in-house designs. Consultant contracts may include provisions for services to be provided during construction. These services may include reviewing shop drawings and assisting with field and design problems.

When consultants are assigned to corridor management projects, consultant contracts are administered by Project Development. The Bridge Design Section provides support to Project Development through technical reviews of structural designs. In addition to participation in the scoping of the project and ensuring that the plans meet Department requirements, the review includes ensuring that all of the documentation specified in Section 2.9.1.2 is provided.

2.9.2 PROJECT INITIATION

2.9.2.1 Design Responsibility

Nearly all bridge design projects include some roadway design. Usually, Project Development has the responsibility for plan preparation of roadway projects that include bridges. On smaller projects with minimal approach work, Bridge Design has responsibility for the design of roadway approaches.

When Project Development has the lead for the design, Bridge Design submits the bridge plans to Project Development for incorporation in the roadway plans at each stage of plan development.

2.9.2.2 Scoping Meeting

A scoping meeting is required for every project. The purpose of the meeting is to determine the limits of the project, define the scope of the project, and discuss the best way to design the project, e.g., widen on one side or both sides. The scope of the project is the basis for preparing the Construction Project Estimate. Scoping meeting participants are invited by letter from the Bridge Design Engineer. Representatives from Team Support, Construction, Maintenance, Environmental Studies, FHWA, Real Estate, Traffic, and Utilities are normally invited. Normally all new Bridge Design projects for a fiscal year are scoped at one time each year. The list of projects includes all of the bridges identified as outlined in Section 2.3.1.1. Large consultant bridge design projects are scoped individually, with the design consultant present.

If the scoping meeting is not held at the site, the Bridge Section must conduct a pre-scoping meeting at the site to become familiar with site conditions and formulate a recommended scope for discussion at the scoping meeting.

The designer must review the bridge safety inspection report in the bridge inspection file for the bridge in question to learn of any problems with the structure—structural damage, flooding, scour, etc.

A realistic project scope will help prevent unnecessary design changes and funding problems in the later stages of the process. When determining the project scope, especially for reconstruction and rehabilitation work, allow for potential deterioration between scoping and actual construction. The rate of deterioration is difficult to predict and the project may be delayed due to lack of funds, environmental issues, or other reasons. Additional inspections and cores may be necessary to assess the deterioration. Underestimating the scope can result in insufficient funding to meet the actual needs two to three years in the future when the project is let to contract.

The designer is responsible for documenting the decisions made at the scoping meeting. A copy is sent to each of the participants of the scoping meeting as well as to those invited who did not attend.

Cost estimates needed to complete the Initiation Form are developed following the scoping meetingand submission of estimates from the relevant individual sections. Scoping for Project Development projects which include bridge work should have representation by the Bridge Design Review Engineer.

2.9.2.3 Project Initiation

A Construction Project Estimate Form is prepared by the designer to initiate the project. Completion of the form entails the following major items:

- name of project;
- project limits;
- a description of the improvement;
- a typical section; and
- an estimate of costs.

Costs must be estimated for the following on the CTP Cost Estimate Form:

- **Location and environmental studies** on Part I. [This is typically not included in bridge design projects; environmental studies costs are included in Part II.]
- **Preliminary engineering (PE)**. Use Part II of the form for estimating the costs of surveys and design engineering. Use 5 to 25 percent of the estimated construction costs to estimate PE costs. PE cost percentages vary inversely with the size of the project. PE costs as a percentage are typically lower on larger projects. The cost should be checked to see if it is reasonable. PE costs include salaries for Department personnel in Bridge Design, Materials and Research, Real Estate, Utilities, Traffic, Survey, Team Support, Quality, Environmental Studies and Hazardous Waste who work on the project.
- **Real estate**. The estimated cost of acquisition of any right-of-way needed for the project is estimated using Part III of the form.
- **Construction**. The estimated cost of construction includes all work that will be included in the construction contract plus utilities, railroads, traffic, construction engineering, and construction contingencies as shown on Part IV of the form. Innovative construction practices such as incentives/disincentives should also be included.
  - **Utilities**. The estimated cost of adjustments or relocations for utilities that qualify for reimbursement.
  - **Railroads**. The estimated cost of railroad force accounts for projects that impact a railroad. These costs are to reimburse the railroad for items such as flaggers, inspectors, and shop drawing review.
  - **Traffic**. The estimated costs of traffic items not included in the contract. These may include permanent traffic control such as installing signal loops and replacing existing signs, and temporary traffic control such as trailblazer signs on detours.
  - **Construction engineering (CE)**. The estimated costs for inspection, testing and contract administration. As with PE costs, CE costs as a percentage of construction costs vary with the size of the project. Normally, 15% is used to estimate CE costs, but estimates ranging from 10 to 25 percent may be appropriate depending on the size of the project.
  - **Construction contingencies** - an allowance for unforeseen items

that were not included in the original construction estimate and for change orders during the construction phase. The allowance is normally 15% for large projects and 20% for small projects. Other amounts are to be approved by the Section Head.

The Bridge Design Project Manager should perform an overall review of the estimate to ensure that it is thorough and reasonable. The Bridge Design Project Manager and the Bridge Design Engineer sign the estimate form. A sample Construction Project Estimate form is shown in Figure 2-2. This form is submitted to the Assistant Director, Design for review and approval. A Project Number Request is then made by the Bridge Design Project Engineer. This request consists of entering project information into the computer, including the location, description of work, project justification, and estimated cost. This information is then reviewed by the Assistant Director, Design, and approved electronically. The Construction Project Estimate is then submitted to Finance by the Assistant Director, Design, for funding approval. After receiving a request for PE funding and the funding is approved, Finance prepares Form FS-1, Project Authorization & Funding, and sends it to the responsible section. If funding is not approved, Form FS-1 is returned to the Chief Engineer.

Form FS-1 must be received by the Bridge Design Section or the Bridge Management Section and the funding authorization entered into the computer before any design work can be started. A sample FS-1 form is shown in Figure 2-3.

A Combined Project Initiation and Project Number Request form provides the designer with information on the class of environmental documentation required and the level of public involvement. The Location and Environmental Studies Section is responsible for preparing the environmental documentation, but information from the designer may be required. The designer must comply with the public involvement specified on the form. A sample form is shown in Figure 2-4.

The classes of environmental documentation are as follows:

- Class I - environmental impact statement (EIS);
- Class II - categorical exclusion (CE); and
- Class III - environmental assessment (EA).

Most bridge design projects are Class II.

The Department's Project Development Process provides four improvement project classifications for public involvement purposes (A, B, C, and D), as described below:

- Level A are large projects that require both Location and Design public hearings.
- Level B projects require a single combined public hearing.
- Level C projects require less formal public involvement such as town meetings or workshops.
- Level D projects generally do not require public involvement.

2.9.2.4 Public Involvement

Contact between the public and DelDOT personnel is sought throughout the transportation planning process to obtain adequate public input. The Project Development Committee makes the determination for the type of public involvement needed for each project, depending on the complexity and impact of the project. The type of public involvement is shown on the Combined Project Initiation and Project Number Request Form. (See Figure 2-4.) As noted on the form, public involvement may include an opportunity to attend a public hearing, meeting or workshop, a plans-available review, or to respond to an "If" notice. Minor projects may have no public involvement. Contacts may also be made through Transportation Advisory Committees. The types of public involvement and responsibilities of the designer are shown below:

- **Public hearings**. A design public hearing is held after the location is approved, but before DelDOT is committed to a specific design. It is held to ensure that an opportunity is afforded for effective participation by persons interested in the specific location and major design features of the project. It provides a public forum for presenting views on major design features, including the social, economic, and environmental effects of alternate designs. A public hearing is required for major projects and for those that may have a significant impact. When the Department determines that a formal presentation is needed, the designer makes the presentation. All presentations, questions, and answers are recorded by a court reporter. The designer prepares an engineering report which must address all of the questions raised at the meeting with recommendations for resolving them. A copy of the engineering report is sent to FHWA only for projects that meet the criteria listed in the Stewardship Agreement (Section 2.9.1.3).
- **Public workshops**. Public meetings may be desirable to inform the public about highway proposals and to obtain information from the public that might affect the choice of alternatives to be considered. They also might identify critical social, economic and environmental effects to be considered. The designer normally conducts the meeting.

More commonly used in bridge design is a plans-available public workshop. No formal presentation is made at a plans-available public workshop. Individuals are given the opportunity to ask questions specific to their interests about the project. The questions and answers are noted but not recorded verbatim. All questions must be addressed. A formal engineering report is not required, but the questions, answers, and recommendations must be documented.

Figure 2-2a
Sample Construction Project Estimate Form

CONSTRUCTION PROJECT ESTIMATE

Estimate No.

1. NAME OF PROJECT Br. 1-167 on Old Mill Road over Orchard Creek — New Castle
Subdivision or Road Name — County

2. LIMITS

Street Name or Road Number	From	To	Length
Old Mill Road (112)		Bridge	30'
		Approaches	360'
		Total	390'

3. ESTIMATE REQUESTED BY: Jiten Soneji (Name), for (check one) ☑ Project initiation ☐ Estimate only — Bridge (Section or Legis. Dist.)

4. DESCRIPTION OF IMPROVEMENT: Replace existing stone arch with precast concrete arch. Reconstruct the roadway approaches and place guardrail. Place riprap in the stream to protect the structure from scour.

4a. METRIC PROJECT Yes ☐ No ☑ If "No", submit English Unit Request form.
4b. PROJECT IN C.I.P. Yes ☐ No ☑ If "Yes", indicate year F.Y. ______

5. TYPICAL SECTION 2 - 12' Lanes, 2 - 4' Shoulders, 2 - 2' Barrier Offsets (This will require a design exception for shoulder width)

6. STATE MAINTAINED ☑ CITY MAINTAINED ☐ PRIVATE ☐ OTHER ☐ (specify) ______

7. COST ESTIMATE:		from C.I.P. estimate form	Estimate prepared by:	Date:
a. Location and Environmental Studies (Part I to be included only for class "I" and "III" projects)	$0	Part I	Barry Benton	21-Oct-04
b. Preliminary Engineering	$215,000	Part II	Barry Benton	21-Oct-04
c. Real Estate	$12,000	Part III	Carolyn O'Donoghue	10-Nov-04
d. Construction *	$779,000	Part IV	Barry Benton	21-Oct-04
e. TOTAL ESTIMATED PROJECT COST	$1,006,000			

* Includes Utilities, Traffic, and C.E.

APPROVED
Valid thru ______ Date
______ Assistant Director, Operations/Preconstruction/Planning
______ Date

Chapter Four

Bridge Load Rating

4.1 INTRODUCTION

The National Bridge Inspection Standards (NBIS) requires each highway department to inspect, prepare reports, and determine load ratings for structures defined as bridges located on all public roads. The NBIS is contained in 23 CFR 650, Subpart C. In Delaware, bridges are defined as having an opening of greater than 20 sq ft [1.86 m^2]. The federal definition of a bridge is "a structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening". Only bridges that meet the federal definition are included in the National Bridge Inventory.

For structural types, materials, and analysis methods not dealt with in this manual, contact the Bridge Management Section.

4.1.1 RESPONSIBILITY

Most bridges in Delaware are state owned and operated. In Delaware, bridges that are not owned and operated by the state are usually owned by cities (Wilmington, Elsmere, and Milford), railroads (CSX, Norfolk Southern), Delaware River and Bay Authority (DRBA), the Department of Natural Resources and Environmental Control (DNREC), or the Army Corps of Engineers. Inspection and rating of these bridges meeting federal requirements are the responsibility of the owner and must be conducted in accordance with the NBIS. Owners forward their bridge inspection and rating results to the Bridge Management Section, which then consolidates the results and forwards them to FHWA for inclusion in the National Bridge Inventory (NBI).

4.1.2 ASSUMPTIONS

Engineers must make assumptions in order to efficiently analyze existing bridges. This is due to the wide variety of structural materials available (e.g., steel, concrete, wrought iron, timber, masonry and/or combination thereof), assortment of structural types, and variations in quality and strength of the materials. These assumptions consider the policies and procedures with which the structures were designed, the recommendations in AASHTO's *The Manual for Bridge Evaluation*, and policies of the DelDOT Bridge Design Section included in this chapter. For new structures, standard design criteria shall be used. During rehabilitation, material testing is usually performed and these values shall be used.

4.1.3 LOAD RATING LEVELS

Load rating analysis of bridges is performed to determine the live load that structures can safely carry. Bridges are rated at three different stress levels, referred to as Inventory Rating, Operating Rating, and Posting Rating.

Inventory rating is the capacity rating for the vehicle type used in the rating that will result in a load level which can safely utilize an existing structure for an indefinite period of time. Inventory load level approximates the design load level for normal service conditions.

Operating rating will result in the absolute maximum permissible load level to which the structure may be subjected for the vehicle type used in the rating. This rating determines the capacity of the bridge for occasional use. Allowing unlimited numbers of vehicles to subject the bridge to the operating level will compromise the bridge life. This value is typically used when evaluating overweight permit vehicle moves.

The posting rating is the capacity rating for the vehicle type used in the rating that will result in a load level which may safely utilize an existing structure on a routine basis for a limited period of time. The posting rating for a bridge is based on inventory level plus a fraction of the difference between inventory and operating. Posting level and fraction is determined using the criteria shown in Figure 4-2.

Structural capacities and loadings are used to analyze the critical members to determine the appropriate load rating. This may lead to load restrictions of the bridge or identification of components that require rehabilitation or other modification to avoid posting of the bridge.

4.1.4 LOAD RESTRICTION POSTING

When a bridge is not able to safely carry the loads allowed by State Statute, it is posted for its reduced capacity. The Bridge Management Section implements load restrictions by preparing a “Load Restriction Resolution,” which is signed by the Chief Engineer. The Bridge Management Section then distributes letters to the proper authorities, including local fire companies, school transportation directors, the Delaware Authority for Regional Transport (DART), Senators, and Representatives. Upon completion of replacement or rehabilitation of a posted structure, the Bridge Management Section prepares a “Removal of Load Restriction Resolution,” signed by the Chief Engineer and distributed as above.

It is the Department’s policy to restrict loads on bridges when the posting-rating factor drops below one for any of the Delaware legal truckloads. See Figures 4-2 and 4-3. The minimum posting is 3 tons [2.7 metric tons]. For further information on posting, contact the Bridge Management Engineer.

Figure 4-3
Enforcement Levels

Level of Enforcement	Degree of Enforcement of Load Limit
1	Vigorous enforcement of weight limit (Interstate, US13 and US113)
2	Moderate enforcement of weight limit (Delaware and US Routes except for those in Level 1)
3	Minimal enforcement of weight limit (usually local roads)

4.2 BRIDGE INSPECTIONS

Prior to rating an existing bridge, the engineer must perform or review results of a recent detailed inspection. The engineer rating the bridge also needs a complete description of the bridge, as-built plans, any modifications since it was built, and its present condition. In lieu of plans, a detailed set of measurements and/or sketches from actual field measurements will be needed.

By law, all bridges on the National Bridge Inventory are required to be inspected at least every two years. Inspection of bridges is done in conformance with AASHTO's *The Manual for Bridge Evaluation*, FHWA's *Recording and Coding Guide for Structure Inventory and Appraisal of the Nation's Bridges*, DelDOT's *Bridge Management Manual*, and DelDOT's *Element Data Collection Manual*. Some structures require more detailed and different types of inspections to determine their actual condition and capacity. Bridges in poor structural condition require more frequent inspections. Bridges are not typically rated as a part of their routine biennial inspections. However, they may be rated as part of any and all inspections at the discretion of the Bridge Management Engineer. Load rating of bridges during inspections is usually prompted by discovery of obvious loss of section, continuing deterioration, and suspected loss of capacity.

When conditions warrant, reduced sections or reduced allowable stresses should be used to obtain a load rating that indicates the actual condition and capacity of the structure. Areas of deterioration would be given special attention during field inspection, since a primary member that is reduced in section may control the capacity of the structure.

4.2.1 INSPECTION TYPES

The following inspection types are included in the NBI Standards: routine; underwater; fracture critical; and special. Routine inspections are regularly scheduled inspections consisting of observations and/or measurements needed to determine the physical and functional condition of the bridge, to identify any changes from initial or previously recorded conditions, and to ensure that the structure continues to satisfy present service requirements. An underwater inspection is an inspection of the underwater portion of a bridge substructure and the surrounding channel which cannot be done visually at low water by wading or probing, generally requiring diving or other appropriate techniques. A fracture critical inspection involves a hands-on inspection of a fracture critical member or member components that may include visual or other nondestructive evaluation. A special inspection is an inspection scheduled at the discretion of the bridge owner, used to monitor a particular known or suspected deficiency. A special inspection can be scheduled with the Bridge Management Section if the structural deficiencies are not documented in sufficient detail in previous reports. All inspection reports are filed and available for review in the Bridge Management Section.

4.2.2 INSPECTION FILES

After field inspection, the Bridge Management Section enters the inspection results into a Pontis database. The Bridge Management Section maintains a file of inspection results for each bridge, along with maintenance records, contract plans, etc. This information indicates the current condition of the bridge, which can then be used in load rating calculations of the structural elements.

4.3 BRIDGE REPLACEMENT AND REHABILITATION RATING

It is the Department's policy to design new bridges and to rehabilitate existing ones for AASHTO live load requirements. This section will discuss the ratings required for new and rehabilitated bridges.

4.3.1 REQUIRED RATINGS

Department policy is to design all new and rehabilitated bridges on state-maintained roads, for an inventory load rating factor of 1.0 or greater for all Delaware legal loads as given in Figure 4-2. In addition, bridges must be designed to fulfill AASHTO design load requirements for LRFD. (Refer to design requirements in this manual.) If a bridge is not designed for the Delaware legal load, the Project Manager shall submit a Design Exception for approval. Design Exceptions are prepared according to Chapter 2, outlining the justification for deviation from the standard. Design Exceptions are recommended by the Project Manager and forwarded through Department Channels for approval by the Chief Engineer. On some rehabilitation projects, such as historical or temporary bridges, however, the scope of work may be limited, making it impractical to provide this minimum rating for the bridge. In this case the bridge shall be designed for an inventory rating as close to 1.0 as possible for the controlling load.

4.3.2 RATED STRUCTURES AND ELEMENTS

All bridge replacement and most bridge rehabilitation projects shall be rated. DelDOT policy is to rate only the bridge superstructure. The need for rating replacement or new structures is to determine the actual load capacity. Load rating rehabilitated structures is required when:

- The bridge has not been previously rated. (Verify with the Bridge Management Section that a current rating of the superstructure using BRASS is on file).
- Testing provides actual material strength.
- Modifications are made that change dead loads on the structure.
- Inspection reveals section loss of members.
- Structural members are replaced or repaired (excluding painting).

When in doubt about the need to do a load rating, check with the Bridge Design and Bridge Management Engineers.

4.4 LOAD RATING METHODS

Load rating methods include analysis and, in some cases, load testing. The Department has a preferred method of load rating and computer software that should be used to perform the analysis. For some types of bridges, other methods of load rating may be required. Load testing may be used under certain circumstances with appropriate methods and procedures.

4.4.1 ANALYSIS METHODS

Analysis methods recognized by the Department include the Load Factor Method, Working Stress Design Method, and Load and Resistance Factor Method. These methods vary based on placing the factor of safety on the loads, structural resistance, or a combination of both.

4.4.1.1 Load Factor Method

The required method of load rating in Delaware is the load factor design (LFD) (ultimate strength) method except as noted in Section 4.2.1.2. Ratings are determined by calculating the ratio of the yield strength of the member to the factored loads, as outlined in Chapter 6 of AASHTO's *The Manual for Bridge Evaluation*.

4.4.1.2 Working Stress Design Method

If rating by the LFD method is not possible, the working (allowable) stress (ASD) method should be used. The working stress method should be used to load rate timber bridges. Other types of bridges may be rated by the working stress design method if approved by the Bridge Management Engineer.

4.4.1.3 Load and Resistance Factor Method

Load and resistance rating methods are under development and not used at this time.

4.4.2 TOOLS

Ratings shall be done using the current version of Wyoming Department of Transportation's BRASS Girder computer program. Note that BRASS data input is in U.S. customary units.

Ratings for timber bridges shall be done by the working stress method using BRASS Girder.

When BRASS cannot be used due to geometry, structure type, or material, other computer programs such as STAAD and other advanced techniques such as finite element analysis, AASHTO-ware products, or hand calculations may be used with approval of the Bridge Management Engineer.

4.4.2.1 BRASS Data Set

Rating input data for each bridge are stored in a BRASS ASCII data file. This data file is developed in a command format. Each line begins with a command which describes data entries referred to as parameters. A sample BRASS data set is shown in Figure 4-4. The BRASS data set is the input for running the BRASS program and calculating the load rating of the bridge. Data sets are prepared for each span of a bridge. An exception is simple span bridges consisting of multiple identical spans where only the worst-case span needs to be analyzed. On continuous spans, all spans should be analyzed due to the influence loads each span has on the others. When complete, the data set shall be forwarded to the Bridge Management Section for use in:

- updating the National Bridge Inventory and
- modifying the overweight vehicle permit routing system.

4.4.2.2 Data Set Standards

Title (TLE) cards shall be the first cards in the data set. Title cards shall contain standard information including bridge number, span number, road carried, road or feature crossed, total number of spans, bridge type, contract number built or rehabilitated under, the year built, and the name of the rater.

Comment cards must be included in the data set and include any and all assumptions made by the Engineer, such as dead load and live load distribution.

File names shall consist of:

For single span: C-NUM.DAT
For multiple span: C-NUM_#.DAT

where:

- C = County Code (1,2, or 3 for New Castle, Kent and Sussex Counties, respectively)
- NUM = Three-digit bridge number (add a fourth digit suffix to bridge number if required)
- # = Span number or description of element rated

Examples: 1-001.dat
1-001A.dat
1-001_s1.dat

Do not use spaces or special characters in the data file name.

4.4.3 LOAD TESTING

Load rating by load testing may be feasible in special cases such as the following:

- When analytical results provide a posting or operating rating factor less than one, but the bridge is otherwise showing no visual signs of distress.
- When record construction plans for the bridge are not available.
- Special types of bridges that cannot be analytically rated.
- When calibrating BRASS data including distribution, fixity, or composite action.

The Department performs load testing by driving a truck of known axle weights over a bridge. Stresses are then measured in the load-carrying members with strain gauges and specially designed data analysis equipment. These axle weights and actual measured stresses are used to calibrate the BRASS input data. A more realistic rating of the bridge can then be obtained for all Delaware legal loads.

4.5 ANALYTICAL STEPS IN LOAD RATING

Analytical steps in load rating are detailed procedures that an engineer goes through in performing a load rating analysis.

The analytical steps required to rate any member are independent of the role played by the member in the overall structure. The method of analysis within any of the steps will vary for each member, depending on the member and the choice of load factor or working stress method, but the function of the calculations will be the same. The following analytical steps are required:

1. Determine section properties.
2. Determine allowable and/or yield stresses.
3. Calculate section capacities.
4. Determine dead load effects.
5. Calculate dead load portion for section capacity.
6. Calculate live load effect.
7. Calculate live load impact and distribution.
8. Calculate allowable live load factor.

The stress levels used to analyze critical members and determine the appropriate inventory and operating rating are outlined in AASHTO's *The Manual for Bridge Evaluation*.

4.5.1 RATED MEMBERS

It is Department policy to rate only the primary load-carrying members in a bridge. This is normally the slabs, girders, trusses, floor beams, stringers, spandrel columns, or arch ring. Concrete box culverts are rated as rigid frames.

Gusset connections of non-load-path-redundant steel truss bridges shall be evaluated during the bridge load rating analysis. The evaluation of gusset connections shall include the evaluation of the connecting plates and fasteners.

Not included in the load rating are the deck slab, piers, abutments, and foundations. The condition of these elements shall be considered, and they shall be assumed to safely carry the loads transmitted to them unless there is evidence of serious deterioration. Main elements and components of the substructure (such as fracture critical steel pier caps, cross beams, or hammerhead piers) whose failure is expected to cause collapse of the bridge, shall be identified for special emphasis during inspection. Refer to AASHTO's *The Manual for Bridge Evaluation* for guidance in load rating substructure elements.

4.5.2 PLAN SHEET RATING NOTES

When ratings are performed in conjunction with the preparation of design drawings, the analysis results are included in the project notes on the plans. It is not necessary to place the results of every Delaware legal load truck on the plans unless a rehabilitated bridge is not designed for the full Delaware legal load and requires posting. Department policy is to place load rating results on the plans for the HS20-44 and controlling truck only. Figure 4-1a is the format used for recording the bridge load rating on design plans.

Bridge maintenance and rehabilitation contracts that do not affect the load-carrying capacity of the structure shall include the optional plan sheet note in Figure 4-1b.

4.6 LIVE LOADS

Bridge capacity depends upon bridge geometry, material strength, condition, structure type, etc. As related to trucks, a bridge's capacity depends not only upon the gross weight, but also upon the number and spacing of the axles and the distribution of load between the axles. Since it is not practical to rate a bridge for the countless axle configurations, Delaware's highway bridges are rated for six standard vehicles which are representative of actual vehicles on the highways. DelDOT's standard rating trucks are HS20-44, S220, S327, S335, S437, T330, T435, and T540. (See Figure 4-5.) Bridges are also rated for the AASHTO HS20 truck and lane load. Non-DelDOT owned highway bridges are rated in the same way.

4.6.1 LOAD DISTRIBUTION

Live load distribution shall be as per AASHTO's *Guide Specification for Distribution of Load or Standard Specifications for Highway Bridges*.

In some cases load distribution may be modified based on the results of load testing. See Section 4.2.3.

4.7 LOAD RATING EXAMPLE

Illustrative load rating examples are given in AASHTO's *The Manual for Bridge Evaluation* and in BRASS. The *Manual* illustrates hand methods of analysis using allowable stress and load factor methods. BRASS gives computer versions of the same. A BRASS data set is shown in Figure 4-4.

4.8 LOAD RATING REPORT

When ratings are performed in conjunction with the preparation of a replacement or rehabilitation project that alters the load ratings of a bridge, a Load Rating Report shall be submitted to the Bridge Management Engineer. The Load Rating Report shall include the following:

- material properties (assumed and/or measured);
- loading assumptions;
- plans or sketches showing all properties and assumptions;
- printout of BRASS data file(s) (where appropriate);
- documentation of structural model used in analysis, if other than BRASS (where appropriate);
- Inventory, Operating, and Posting summary for HS20 and all legal loads;
- electronic copies of data file(s).

The Load Rating Report shall be submitted as soon as possible after Final Construction Plans are complete.

13.9.7 CONSULTANT CONSTRUCTION SUPPORT

Consultants who prepare design plans are typically retained to assist during construction. A separate contract between the Department and consultant for construction services should be prepared for this purpose. Typical assistance consultants provide during construction include:

- Attendance and support at pre-bid and preconstruction meetings.
- Assistance in plan interpretation.
- Review of working drawings.
- Preparation of plan revisions.
- Analysis and recommendations of unforeseen conditions.

Occasionally, consultants also provide more extensive construction support such as:

- On-call assistance with construction inspection and acceptance.
- Review of contractor plan change proposals.
- Attendance and support at progress meetings and/or public meetings.

Consultant assistance needs to be provided in a timely manner to ensure that the project is not delayed and that the Department is responsive to the contractor.

13.9.8 AS-BUILT PLANS

During construction, not all details of the design plans may be followed exactly. Reasons for plan changes may be unforeseen or changed conditions in the field, plan revisions, value engineering proposals, deleted work, construction errors, etc.

As-builts are master sets of plans initially created and maintained by the inspection staff during construction. As changes occur, this set of plans is updated to reflect the actual as-built condition. Once the project is completed, the as-builts are forwarded back to the Design Project Manager. The Design Project Manager or his representative transfers as-built information onto the Department's file copies of the plans, which are then archived to serve as a permanent record of the bridge.

Marking as-builts is done in red in the field and later transferred to the electronic version of the plans. Once all as-built information is transferred to the electronic version of he plans, a final raster image of the plans is created (typically cal files). These files are then archived for future reference in the Department's database.

13.10 CONTRACTOR SUBMISSIONS

Contractors must make material and working drawing submissions as required by Setion 100 of the Standard Specifications. A working drawing submittal process flow chart is shown in the Standard Specifications, which indicates the flow of working drawings, number of copies required, and time limit for review. In some cases, the construction group may revise the standard submission flow to accelerate the project.

In most cases, the Designer will not communicate directly with the contractor; however, thereare exceptions when direct communication between the contractor and Designer is in the best interest of the Department. Designers should normally communicate with the contractor either through or in the presence of construction group personnel. Direct communication between the Designer and contractor shall only take place when authorized by the construction group. When the construction group is not a party to direct communication between the Designer and contractor, the Designer must provide the construction group with a summary of the discussion.

13.10.1 WORKING DRAWING SUBMISSIONS

Designers are responsible for ensuring that working drawing submittals are in general conformity with the plans and specifications. Designer check to ensure that member sizes are accurate and do a cursory check of structural calculations. In some cases, contractors submit recommended changes to the plans due to constructability or material availability, which Designers must assess. Designers write comments on all copies of submissions in red and return them to the construction group. Designers stamp submissions in accordance with the Standard Specifications Section 100. One copy of stamped submissions is kept in the Bridge Design files.

Some working drawings include structural materials to be fabricated. Once approved by the Designer, the required number of stamped copies of these plans shall be forwarded to the Materials and Research Engineer and the remainder sent back to the construction group. The Materials and Research Engineer then arranges for shop inspection of fabricated members.

Designers shall make review of contractor submissions a high priority, insuring that these submissions are reviewed and returned to the construction group as soon as possible but in no more than 30 days.

When a submission is not approved, the Designer should immediately alert construction group personnel, since this may affect the construction schedule. Designers should avoid the following:

- Making major changes to contractor submissions because this tends to decrease the contractor's responsibility.
- Making changes that are inconsistent with the contract documents.

When Designers make changes to a submission, the construction group should be informed so that the change can be quickly coordinated with the Contractor.

13.10.2 MATERIAL SUBMISSIONS

Product-specific submissions, including concrete mix designs, are forwarded directly from the construction group to the Materials and Research Engineer for review. Designers do not stamp these submissions. If a materials submission is mistakenly sent to the Designer, it should be forwarded to the Materials and Research Engineer.

In all cases, the construction group Engineer shall be copied on submission transmittals and correspondence initiated by the Designer.

13.10.3 CONSTRUCTION LOADS

Contractors must submit shop drawings and signed and sealed calculations, and get approval from the Bridge Design Engineer to exceed the load restrictions identified in the plans. This includes changes in the size and location of loads such as material stockpiles, vehicular traffic (such as shifting travel lanes to shoulders), or construction equipment (including crane loading). All primary members, including connections, shall be analyzed for the proposed anticipated construction loads. All stresses for existing and proposed members shall be within allowable ranges for strength, service, and fatigue as directed by the *AASHTO Specifications*.

The construction scheme identified in the plans is only one possibility. If the contractor develops a method for the project, the contractor must evaluate the effect of construction loads on the bridge's primary load-carrying members, which includes the deck slabs, concrete box culverts girders, trusses, floor beams, stringers, spandrel columns, arch ring, gusset connections (including the connecting plates and fasteners) of non-load-path-redundant steel truss bridges, piers, abutments, foundations and main elements and components of the substructure (such as fracture critical steel pier caps, cross beams, or hammerhead piers).

Refer to AASHTO's *The Manual for Bridge Evaluation* for additional guidance.

13.11 PLAN CHANGES

Occasionally, contract requirements may have to be changed during construction for reasons including the following:

- Unforeseen physical conditions
- Existing structures not built per original plans
- Structural condition differing from those in inspection reports.
- Features missed during survey
- Utility conflicts
- Subsurface irregularities
- Political requests

Depending on the extent and complexity of the change, a plan revision or field change may be required. All change orders shall be reviewed and approved by the Designer. Situations involving structural changes, public safety, and/or more complex problems are referred from the construction group to the Design Project Manager. Design Project Managers should consult with construction group personnel before making a final decision related to plan changes.

13.11.1 PLAN REVISIONS

Plan revisions are required for any changes to the plan, profile, or features of the project.

Design Project Managers will take the lead in obtaining approval for the change and preparing plan revisions. Before implementing changes, the Design Project Manager should contact the Finance Section to discuss the change and verify whether funding is available.

Design Project Managers will make revisions to appropriate sheets of the plans along with computation of new quantities. Design Project Managers should coordinate with the construction group on the required number of sheets to forward. Design Project Managers will send written justification to Finance indicating the changes required and requesting any increase or decrease in funding.

Plan revisions shall be marked on the plans as indicated in the CADD Manual.

13.11.2 FIELD CHANGES

Field changes are relatively minor changes in which a plan revision is not required. In most cases the construction group will coordinate field changes with the Design Project Manager. The construction group is responsible for coordinating any funding needs with Finance. The changes made will be marked on the as-built plans.

13.11.3 COST ANALYSIS

Changes to project plans may require a cost analysis to be performed if the scope and complexity of the work has changed and is not representative of the contract price. When requested by the construction group, Design Project Managers will perform a cost analysis for use in determining a fair price for the work required.

Typically, the construction group also negotiates with the contractor on the price for additional work. When the contractor and Design Project Manager's estimated costs vary considerably, the construction group will continue to negotiate with the contractor and, if necessary, pay for the work by force account.

13.11.4 CONSTRUCTION CLAIMS

Design Project Managers may be asked to support the construction group in construction claim hearings held with the contractor. For this reason, the Design Project Manager shall insure that accurate records are kept to enable fair evaluation of the claim.

2.5.5 FUTURE WIDENING

When it is reasonably certain that the bridge will have to be widened in the near future, the substructure should be designed to accommodate the widening. The substructure on the median side of divided highways should be constructed with the original bridge because of the difficulty of constructing it under traffic.

2.5.6 CONTEXT SENSITIVE DESIGN

A context sensitive design simultaneously advances the objectives of safety, mobility, enhancement of the natural environment, and preservation of community values. All bridge projects should balance these objectives as appropriate for each location. Designers should use the flexibility within the *Road Design Manual* to achieve these objectives. Guidance is available from the FHWA *Flexibility in Highway Design* and the *Green Book*.

2.6 DESIGN LOADS

DelDOT adopts all AASHTO design loads and Delaware legal loads.

2.6.1 LIVE LOADS

Refer to the *AASHTO Specifications* for AASHTO live loads.

The above loadings are for load ratings. These loadings are not used for LRFD.

2.6.2 DEAD LOADS

Refer to Section 3.5, Permanent Loads, in the *AASHTO Specifications*.

2.6.3 CONSTRUCTION LOADS

During design, all primary members, including connections, shall be analyzed for anticipated construction loads. The designer shall review as-built plans, archived shop drawings, and previous inspection notes and drawings, along with personal field inspection to ensure the size and condition of structural members. All stresses for existing and proposed members shall be within allowable ranges for strength, service, and fatigue as directed by the *AASHTO Specifications*.

Analysis shall be required for shifting travel lanes to shoulders, anticipated stockpiling of materials or equipment (including crane loading), or any other significant loading anticipated.

Plan notes and specifications shall be clearly written to limit construction equipment and stockpile sizes to ensure members stay within allowable stress limits and to direct the contractor to provide calculations and shop drawings for any deviation.

2.7 BRIDGE LOAD RATING

The designer is required to calculate load ratings for all structures as a part of the design. This requirement applies to all structures—complete replacement, rehabilitation, or new bridge. Refer to Chapter 4 for load rating requirements. In addition to the design of the structure using HL-93, a minimum inventory rating of one will be achieved for all Delaware legal loads.

The calculated ratings must be included in the project notes of the contract plans. Refer to Figure 4-2 for a sample summary format.

2.8 PLAN PRESENTATION

Bridge construction plans shall conform to DelDOT standards.

input, output, and the name and version of the software);

- design checklist; and
- any design exceptions.

The documentation should be kept in notebooks or folders for permanent storage in the contract file. With each plan submission, a copy of design computations and printouts shall be submitted so that they can be reviewed; they must include the date and the name/initials of the designer who performed the computations and the person who checked them on each sheet. Added to this will be the date and the name/initials of the DelDOT reviewer following review of the computations. The cover sheet for the calculations shall have signature lines for the designer, checker and reviewer to recommend what is contained therein. By the final plan submission, consultant designers should submit all of the original documentation to the Bridge Design Engineer. Any changes to the documentation should be submitted by the time construction is completed.

2.9.1.3 Stewardship Agreement

The Stewardship Agreement between DelDOT and FHWA defines responsibilities for program, project, and process reviews. This agreement is updated annually; the most recent agreement should be referred to. Under this Agreement, all federal-aid projects will be reviewed and approved within DelDOT and not involve FHWA unless:

- the project is a 3R or 4R project on the Interstate System (NHS) and the estimated construction cost exceeds one million dollars;
- the project is a 4R project on the National Highway System (NHS) and the estimated construction cost exceeds one million dollars;
- the project is a bridge estimated to cost more than 10 million dollars; or
- the project is unique and the Department requests FHWA involvement.

Since project costs tend to escalate through the design process, all federal-aid projects on the NHS should be reviewed with the Bridge Design Engineer at initiation to determine whether FHWA should be involved.

A 4R bridge project shall be defined as a project involving complete bridge replacement or rehabilitation including complete deck replacement. A bridge preservation project shall be defined as one that does not include complete deck replacement. These projects may include such items as deck overlay, joint replacement, cleaning and painting, seismic retrofit, scour countermeasure installation, and substructure rehabilitation.

2.9.1.4 Design Consultants

Design consultants are engaged to supplement in-house design staff and for design of unique structures. Consultants are selected through the Department's selection process. Design contracts are typically open-end contracts for a specified time period with an upset fee limit. The successful consultants are assigned projects for design as needed during the contract period. Assigned projects are scoped with the consultant, who then prepares a formal scope and cost proposal for the design. Upon approval of the cost proposal and funding, the Bridge Design Engineer issues a notice to proceed. Refer to the *Professional Services Procurement Manual* for more detail.

The Bridge Design Project Manager monitors consultant progress and conducts periodic technical reviews on open-end consultant contracts, similar to in-house

Chapter Four

Bridge Load Rating

4.1 INTRODUCTION

The National Bridge Inspection Standards (NBIS) requires each highway department to inspect, prepare reports, and determine load ratings for structures defined as bridges located on all public roads. The NBIS is contained in 23 CFR 650, Subpart C. In Delaware, bridges are defined as having an opening of greater than 20 sq ft [1.86 m^2]. The federal definition of a bridge is "a structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening". Only bridges that meet the federal definition are included in the National Bridge Inventory.

For structural types, materials, and analysis methods not dealt with in this manual, contact the Bridge Management Section.

4.1.1 RESPONSIBILITY

Most bridges in Delaware are state owned and operated. In Delaware, bridges that are not owned and operated by the state are usually owned by cities (Wilmington, Elsmere, and Milford), railroads (CSX, Norfolk Southern), Delaware River and Bay Authority (DRBA), the Department of Natural Resources and Environmental Control (DNREC), or the Army Corps of Engineers. Inspection and rating of these bridges meeting federal requirements are the responsibility of the owner and must be conducted in accordance with the NBIS. Owners forward their bridge inspection and rating results to the Bridge Management Section, which then consolidates the results and forwards them to FHWA for inclusion in the National Bridge Inventory (NBI).

4.1.2 ASSUMPTIONS

Engineers must make assumptions in order to efficiently analyze existing bridges. This is due to the wide variety of structural materials available (e.g., steel, concrete, wrought iron, timber, masonry and/or combination thereof), assortment of structural types, and variations in quality and strength of the materials. These assumptions consider the policies and procedures with which the structures were designed, the recommendations in AASHTO's *The Manual for Bridge Evaluation,* and policies of the DelDOT Bridge Design Section included in this chapter. For new structures, standard design criteria shall be used. During rehabilitation, material testing is usually performed and these values shall be used.

Figure 4-3
Enforcement Levels

Level of Enforcement	Degree of Enforcement of Load Limit
1	Vigorous enforcement of weight limit (Interstate, US13 and US113)
2	Moderate enforcement of weight limit (Delaware and US Routes except for those in Level 1)
3	Minimal enforcement of weight limit (usually local roads)

4.2 BRIDGE INSPECTIONS

Prior to rating an existing bridge, the engineer must perform or review results of a recent detailed inspection. The engineer rating the bridge also needs a complete description of the bridge, as-built plans, any modifications since it was built, and its present condition. In lieu of plans, a detailed set of measurements and/or sketches from actual field measurements will be needed.

By law, all bridges on the National Bridge Inventory are required to be inspected at least every two years. Inspection of bridges is done in conformance with AASHTO's *The Manual for Bridge Evaluation*, FHWA's *Recording and Coding Guide for Structure Inventory and Appraisal of the Nation's Bridges*, DelDOT's *Bridge Management Manual*, and DelDOT's *Element Data Collection Manual*. Some structures require more detailed and different types of inspections to determine their actual condition and capacity. Bridges in poor structural condition require more frequent inspections. Bridges are not typically rated as a part of their routine biennial inspections. However, they may be rated as part of any and all inspections at the discretion of the Bridge Management Engineer. Load rating of bridges during inspections is usually prompted by discovery of obvious loss of section, continuing deterioration, and suspected loss of capacity.

When conditions warrant, reduced sections or reduced allowable stresses should be used to obtain a load rating that indicates the actual condition and capacity of the structure. Areas of deterioration would be given special attention during field inspection, since a primary member that is reduced in section may control the capacity of the structure.

4.2.1 INSPECTION TYPES

The following inspection types are included in the NBI Standards: routine; underwater; fracture critical; and special. Routine inspections are regularly scheduled inspections consisting of observations and/or measurements needed to determine the physical and functional condition of the bridge, to identify any changes from initial or previously recorded conditions, and to ensure that the structure continues to satisfy present service requirements. An underwater inspection is an inspection of the underwater portion of a bridge substructure and the surrounding channel which cannot be done visually at low water by wading or probing, generally requiring diving or other appropriate techniques. A fracture critical inspection involves a hands-on inspection of a fracture critical member or member components that may include visual or other nondestructive evaluation. A special inspection is an inspection scheduled at the discretion of the bridge owner, used to monitor a particular known or suspected deficiency. A special inspection can be scheduled with the Bridge Management Section if the structural deficiencies are not documented in sufficient detail in previous reports. All inspection reports are filed and available for review in the Bridge Management Section.

4.2.2 INSPECTION FILES

After field inspection, the Bridge Management Section enters the inspection results into a Pontis database. The Bridge Management Section maintains a file of inspection results for each bridge, along with maintenance records, contract plans, etc. This information indicates the current condition of the bridge, which can then be used in load rating calculations of the structural elements.

4.3 BRIDGE REPLACEMENT AND REHABILITATION RATING

It is the Department's policy to design new bridges and to rehabilitate existing ones for AASHTO live load requirements. This section will discuss the ratings required for new and rehabilitated bridges.

4.3.1 REQUIRED RATINGS

Department policy is to design all new and rehabilitated bridges on state-maintained roads, for an inventory load rating factor of 1.0 or greater for all Delaware legal loads as given in Figure 4-2. In addition, bridges must be designed to fulfill AASHTO design load requirements for LRFD. (Refer to design requirements in this manual.) If a bridge is not designed for the Delaware legal load, the Project Manager shall submit a Design Exception for approval. Design Exceptions are prepared according to Chapter 2, outlining the justification for deviation from the standard. Design Exceptions are recommended by the Project Manager and forwarded through Department Channels for approval by the Chief Engineer. On some rehabilitation projects, such as historical or temporary bridges, however, the scope of work may be limited, making it impractical to provide this minimum rating for the bridge. In this case the bridge shall be designed for an inventory rating as close to 1.0 as possible for the controlling load.

4.3.2 RATED STRUCTURES AND ELEMENTS

All bridge replacement and most bridge rehabilitation projects shall be rated. DelDOT policy is to rate only the bridge superstructure. The need for rating replacement or new structures is to determine the actual load capacity. Load rating rehabilitated structures is required when:

- The bridge has not been previously rated. (Verify with the Bridge Management Section that a current rating of the superstructure using BRASS is on file).
- Testing provides actual material strength.
- Modifications are made that change dead loads on the structure.
- Inspection reveals section loss of members.
- Structural members are replaced or repaired (excluding painting).

When in doubt about the need to do a load rating, check with the Bridge Design and Bridge Management Engineers.

4.4 LOAD RATING METHODS

Load rating methods include analysis and, in some cases, load testing. The Department has a preferred method of load rating and computer software that should be used to perform the analysis. For some types of bridges, other methods of load rating may be required. Load testing may be used under certain circumstances with appropriate methods and procedures.

4.4.1 ANALYSIS METHODS

Analysis methods recognized by the Department include the Load Factor Method, Working Stress Design Method, and Load and Resistance Factor Method. These methods vary based on placing the factor of safety on the loads, structural resistance, or a combination of both.

4.4.1.1 Load Factor Method

The required method of load rating in Delaware is the load factor design (LFD) (ultimate strength) method except as noted in Section 4.2.1.2. Ratings are determined by calculating the ratio of the yield strength of the member to the factored loads, as outlined in Chapter 6 of AASHTO's *The Manual for Bridge Evaluation*.

4.4.1.2 Working Stress Design Method

If rating by the LFD method is not possible, the working (allowable) stress (ASD) method should be used. The working stress method should be used to load rate timber bridges. Other types of bridges may be rated by the working stress design method if approved by the Bridge Management Engineer.

4.4.1.3 Load and Resistance Factor Method

Load and resistance rating methods are under development and not used at this time.

4.4.2 TOOLS

Ratings shall be done using the current version of Wyoming Department of Transportation's BRASS Girder computer program. Note that BRASS data input is in U.S. customary units.

Ratings for timber bridges shall be done by the working stress method using BRASS Girder.

When BRASS cannot be used due to geometry, structure type, or material, other computer programs such as STAAD and other advanced techniques such as finite element analysis, AASHTO-ware products, or hand calculations may be used with approval of the Bridge Management Engineer.

4.4.2.1 BRASS Data Set

Rating input data for each bridge are stored in a BRASS ASCII data file. This data file is developed in a command format. Each line begins with a command which describes data entries referred to as parameters. A sample BRASS data set is shown in Figure 4-4. The BRASS data set is the input for running the BRASS program and calculating the load rating of the bridge. Data sets are prepared for each span of a bridge. An exception is simple span bridges consisting of multiple identical spans where only the worst-case span needs to be analyzed. On continuous spans, all spans should be analyzed due to the influence loads each span has on the others. When complete, the data set shall be forwarded to the Bridge Management Section for use in:

4.5 ANALYTICAL STEPS IN LOAD RATING

Analytical steps in load rating are detailed procedures that an engineer goes through in performing a load rating analysis.

The analytical steps required to rate any member are independent of the role played by the member in the overall structure. The method of analysis within any of the steps will vary for each member, depending on the member and the choice of load factor or working stress method, but the function of the calculations will be the same. The following analytical steps are required:

1. Determine section properties.
2. Determine allowable and/or yield stresses.
3. Calculate section capacities.
4. Determine dead load effects.
5. Calculate dead load portion for section capacity.
6. Calculate live load effect.
7. Calculate live load impact and distribution.
8. Calculate allowable live load factor.

The stress levels used to analyze critical members and determine the appropriate inventory and operating rating are outlined in AASHTO's *The Manual for Bridge Evaluation*.

4.5.1 RATED MEMBERS

It is Department policy to rate only the primary load-carrying members in a bridge. This is normally the slabs, girders, trusses, floor beams, stringers, spandrel columns, or arch ring. Concrete box culverts are rated as rigid frames.

Gusset connections of non-load-path-redundant steel truss bridges shall be evaluated during the bridge load rating analysis. The evaluation of gusset connections shall include the evaluation of the connecting plates and fasteners.

Not included in the load rating are the deck slab, piers, abutments, and foundations. The condition of these elements shall be considered, and they shall be assumed to safely carry the loads transmitted to them unless there is evidence of serious deterioration. Main elements and components of the substructure (such as fracture critical steel pier caps, cross beams, or hammerhead piers) whose failure is expected to cause collapse of the bridge, shall be identified for special emphasis during inspection. Refer to AASHTO's *The Manual for Bridge Evaluation* for guidance in load rating substructure elements.

4.5.2 PLAN SHEET RATING NOTES

When ratings are performed in conjunction with the preparation of design drawings, the analysis results are included in the project notes on the plans. It is not necessary to place the results of every Delaware legal load truck on the plans unless a rehabilitated bridge is not designed for the full Delaware legal load and requires posting. Department policy is to place load rating results on the plans for the HS20-44 and controlling truck only. Figure 4-1a is the format used for recording the bridge load rating on design plans.

Bridge maintenance and rehabilitation contracts that do not affect the load-carrying capacity of the structure shall include the optional plan sheet note in Figure 4-1b.

4.6 LIVE LOADS

Bridge capacity depends upon bridge geometry, material strength, condition, structure type, etc. As related to trucks, a bridge's capacity depends not only upon the gross weight, but also upon the number and spacing of the axles and the distribution of load between the axles. Since it is not practical to rate a bridge for the countless axle configurations, Delaware's highway bridges are rated for six standard vehicles which are representative of actual vehicles on the highways. DelDOT's standard rating trucks are HS20-44, S220, S327, S335, S437, T330, T435, and T540. (See Figure 4-5.) Bridges are also rated for the AASHTO HS20 truck and lane load. Non-DelDOT owned highway bridges are rated in the same way.

4.6.1 LOAD DISTRIBUTION

Live load distribution shall be as per AASHTO's *Guide Specification for Distribution of Load or Standard Specifications for Highway Bridges*.

In some cases load distribution may be modified based on the results of load testing. See Section 4.2.3.

4.7 LOAD RATING EXAMPLE

Illustrative load rating examples are given in AASHTO's *The Manual for Bridge Evaluation* and in BRASS. The *Manual* illustrates hand methods of analysis using allowable stress and load factor methods. BRASS gives computer versions of the same. A BRASS data set is shown in Figure 4-4.

4.8 LOAD RATING REPORT

When ratings are performed in conjunction with the preparation of a replacement or rehabilitation project that alters the load ratings of a bridge, a Load Rating Report shall be submitted to the Bridge Management Engineer. The Load Rating Report shall include the following:

- material properties (assumed and/or measured);
- loading assumptions;
- plans or sketches showing all properties and assumptions;
- printout of BRASS data file(s) (where appropriate);
- documentation of structural model used in analysis, if other than BRASS (where appropriate);
- Inventory, Operating, and Posting summary for HS20 and all legal loads;
- electronic copies of data file(s).

The Load Rating Report shall be submitted as soon as possible after Final Construction Plans are complete.

between the Designer and contractor, the Designer must provide the construction group with a summary of the discussion.

13.10.1 WORKING DRAWING SUBMISSIONS

Designers are responsible for ensuring that working drawing submittals are in general conformity with the plans and specifications. Designer check to ensure that member sizes are accurate and do a cursory check of structural calculations. In some cases, contractors submit recommended changes to the plans due to constructability or material availability, which Designers must assess. Designers write comments on all copies of submissions in red and return them to the construction group. Designers stamp submissions in accordance with the Standard Specifications Section 100. One copy of stamped submissions is kept in the Bridge Design files.

Some working drawings include structural materials to be fabricated. Once approved by the Designer, the required number of stamped copies of these plans shall be forwarded to the Materials and Research Engineer and the remainder sent back to the construction group. The Materials and Research Engineer then arranges for shop inspection of fabricated members.

Designers shall make review of contractor submissions a high priority, insuring that these submissions are reviewed and returned to the construction group as soon as possible but in no more than 30 days.

When a submission is not approved, the Designer should immediately alert construction group personnel, since this may affect the construction schedule. Designers should avoid the following:

- Making major changes to contractor submissions because this tends to decrease the contractor's responsibility.
- Making changes that are inconsistent with the contract documents.

When Designers make changes to a submission, the construction group should be informed so that the change can be quickly coordinated with the Contractor.

13.10.2 MATERIAL SUBMISSIONS

Product-specific submissions, including concrete mix designs, are forwarded directly from the construction group to the Materials and Research Engineer for review. Designers do not stamp these submissions. If a materials submission is mistakenly sent to the Designer, it should be forwarded to the Materials and Research Engineer.

In all cases, the construction group Engineer shall be copied on submission transmittals and correspondence initiated by the Designer.

13.10.3 CONSTRUCTION LOADS

Contractors must submit shop drawings and signed and sealed calculations, and get approval from the Bridge Design Engineer to exceed the load restrictions identified in the plans. This includes changes in the size and location of loads such as material stockpiles, vehicular traffic (such as shifting travel lanes to shoulders), or construction equipment (including crane loading). All primary members, including connections, shall be analyzed for the proposed anticipated construction loads. All stresses for existing and proposed members shall be within allowable ranges for strength, service, and fatigue as directed by the *AASHTO Specifications*.

The construction scheme identified in the plans is only one possibility. If the contractor develops a method for the project, the contractor must evaluate the effect of construction loads on the bridge's primary load-carrying members, which includes the deck slabs, concrete box culverts girders, trusses, floor beams, stringers, spandrel columns, arch ring, gusset connections (including the connecting plates and fasteners) of non-load-path-redundant steel truss bridges, piers, abutments, foundations and main elements and components of the substructure (such as fracture critical steel pier caps, cross beams, or hammerhead piers).

Refer to AASHTO's *The Manual for Bridge Evaluation* for additional guidance.

13.11 PLAN CHANGES

Occasionally, contract requirements may have to be changed during construction for reasons including the following:

- Unforeseen physical conditions
- Existing structures not built per original plans
- Structural condition differing from those in inspection reports.
- Features missed during survey
- Utility conflicts
- Subsurface irregularities
- Political requests

Depending on the extent and complexity of the change, a plan revision or field change may be required. All change orders shall be reviewed and approved by the Designer. Situations involving structural changes, public safety, and/or more complex problems are referred from the construction group to the Design Project Manager. Design Project Managers should consult with construction group personnel before making a final decision related to plan changes.

13.11.1 PLAN REVISIONS

Plan revisions are required for any changes to the plan, profile, or features of the project.

Design Project Managers will take the lead in obtaining approval for the change and preparing plan revisions. Before implementing changes, the Design Project Manager should contact the Finance Section to discuss the change and verify whether funding is available.

Design Project Managers will make revisions to appropriate sheets of the plans along with computation of new quantities. Design Project Managers should coordinate with the construction group on the required number of sheets to forward. Design Project Managers will send written justification to Finance indicating the changes required and requesting any increase or decrease in funding.

Plan revisions shall be marked on the plans as indicated in the CADD Manual.

13.11.2 FIELD CHANGES

Field changes are relatively minor changes in which a plan revision is not required. In most cases the construction group will coordinate field changes with the Design Project Manager. The construction group is responsible for coordinating any funding needs with Finance. The changes made will be marked on the as-built plans.

13.11.3 COST ANALYSIS

Changes to project plans may require a cost analysis to be performed if the scope and complexity of the work has changed and is not representative of the contract price. When requested by the construction group, Design Project Managers will